

# Another World: The composition and consequences of the Introduced Mammal fauna of New Zealand

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## ABSTRACT

Terrestrial mammals are a geologically recent addition to New Zealand ecosystems. However, in a very short space of time, they have become a significant feature of the environment. Introduced mammals form the basis of the country's economy, they provide world-recognised sporting opportunities, and are considered by many as an enriching part of the New Zealand landscape. However, exotic mammals are also responsible for significant ecological and economic damage, and are often the focus of intensive, sustained and costly control efforts. In economic terms, many domesticated mammal species are perceived as vital and integral resources, while ecologically, wild and feral mammals are still viewed as foreign and unwelcome. In comparison to areas with large endemic mammal faunas such as Australia, the science of mammalogy in New Zealand is primarily the synthesis of the study of mammalian biology, ecology, invasion biology and human perception, and represents a globally unique perspective. New Zealand mammalogists have utilised this grounding to make significant contributions to mammalogy and ecology, both locally and internationally.

**Key words:** Australia, conservation, exotic, feral, introduction, mammal, New Zealand

## Introduction

On a global scale, Australia and New Zealand are geographical housemates, separated at their widest point by the 1,900 km of the Tasman Sea. They lie in the same physical region, and share a common contemporary cultural heritage. Both countries are developed western societies whose economies primarily rely on the use of natural resources, and both nations have established and active scientific communities.

However, geologically and ecologically, they are worlds apart. The Australian landmass is large, geologically old, stable and weathered, and is the centre of endemism for a large and diverse array of flora and fauna (Augee and Fox 2000). In comparison, the main islands of New Zealand are relatively small geographically, young and dynamic geologically, and are home to a rather skewed complement of endemic species (Cooper and Millener 1993; Augee and Fox 2000). In biological terms, one of the areas where these differences are most apparent is the composition and nature of the contemporary mammal fauna of both countries. While approximately 92% of the 379 mammal species present in Australia are native to that country (Strahan 1995), only 23% of the 46 species of land-breeding mammals of New Zealand have a similar status (King 1990a). This paucity of endemic terrestrial mammals has profound and far-reaching consequences for both the ecology of New Zealand, as well as for the nature, focus and practice of New Zealand mammalogy.

It is my intention in this paper to present a brief history of the mammals of New Zealand, including the composition and nature of endemic New Zealand ecosystems, and the

role that subsequent human introductions of mammal species has played in shaping the current state of ecological systems in that country. This discussion will highlight the way these processes have, in turn, influenced how contemporary mammalogy is viewed and conducted in New Zealand, and how the perception and practice of the discipline differs between New Zealand and other countries with large endemic mammal faunas.

## The ecology of pre-human New Zealand

To understand the present day composition of the mammal fauna of New Zealand, and the part these species play in New Zealand ecosystems, we must first consider the composition and ecology of pre-human New Zealand ecosystems. When the fledgling 'proto-New Zealand' separated from the Gondwanan landmass in the late Cretaceous (90 – 65 m.y.a.) (Cooper and Millener 1993; Augee and Fox 2000), it took a subset of the existing fauna with it; a fauna dominated at the time by the invertebrate, amphibian, reptile and avian lineages (Daugherty *et al.* 1993). Crucially for the evolution of New Zealand ecosystems, the separation of the landmasses occurred prior to the main mammalian radiation during the Oligocene (37-24 m.y.a.), so that the fledgling country, with the exception of the Mystacinid bats (Worthy and Holdaway 2002), was entirely devoid of mammals for at least 30-40 million years (Cooper and Millener 1993; Towns and Ballantine 1993; Augee and Fox 2000). In addition, the only mammals that could

reach New Zealand were those that could fly or swim (Table 1), so that for a period of 65 million years, until the arrival of humans approximately 800–1000 years ago, there were no ground-dwelling, terrestrial mammals on the main New Zealand islands (King 1990a). *Mystacina* (small, insectivorous bats weighing 10–30 g) were almost certainly abundant predators in early New Zealand, and may have been a strong selective force on components of the invertebrate fauna, as well as having an important role in some plant pollination syndromes (Webb and Kelly 1993; Worthy and Holdaway 2002). Nevertheless, terrestrial mammals have been at most a minor selective force in the evolution of New Zealand ecosystems.

The paucity of terrestrial mammals in New Zealand for the majority of its geological history has had a number of important consequences. With no or few mammalian competitors present, the endemic fauna radiated and adapted to fill a number of ecological niches claimed elsewhere by the rapidly evolving Class Mammalia. Biological oddities abound, such as the giant weta *Deinacrida* spp., which is a large flightless orthopteran that forages on the forest floor in a manner akin to a large invertebrate mouse (Daugherty *et al.* 1993); or the kiwi *Apteryx* spp., a small flightless ratite, and the only bird species with nostrils at the end of its bill, that roams the forest floor at night like a shaggy avian bandicoot.

Even more crucially, the almost complete lack of mammalian predators (with the exception of the Mystacinid bats) also made the maintenance of energetically expensive anti-predator defences unnecessary and, as a consequence, many invertebrate and avian species developed gigantism and/or lost the ability to fly (25–35 % of avian species were flightless

at the time of the first human colonisation of New Zealand) (McNab 1994). Many species developed K-selected life history strategies, which suited them well in a pre-human, terrestrial-mammal-free New Zealand. However, it also made them extremely vulnerable to the rapid environmental disturbance that accompanied the human discovery and colonisation of the country.

## Effects and consequences of human colonisation of New Zealand

Humans, and their associated mammals, have only been present in the New Zealand environment with any certainty for approximately 1000 years (Davidson 1984; but see below) and the ecological impacts of these invaders on endemic ecosystems have occurred in the space of a geological heart beat. The consequences of this human-lead invasion have been more serious than in many other countries due to the unique biological conditions existing in pre-human New Zealand, and the effects of this large unplanned 'ecological experiment' continue today.

One of the most important and pervasive changes that has accompanied human colonisation has been widespread habitat modification. This started with the first Polynesian settlers and was continued by the later waves of European colonists. At the time of human discovery, approximately 78% of New Zealand was covered in forest, a mix of *Nothofagus* spp. (Fagaceae) and Podocarpaceae, while only 5% of the landcover was grassland (King 1990a). By the time the first Europeans arrived in the late 1700s, forest cover was down to around 53%, with a corresponding increase in grassland to 30%. Habitat modification accelerated with the European settlers, with clearing of

**Table 1.** Endemic and native New Zealand mammals present at the time of European discovery and colonisation (1780s). Status refers to species that are widespread (W), locally common (L), rare (R), extinct (E), or never established (NE). Modified from King 1990.

Scientific name	Common name	Distribution	Status
<b>Order Chiroptera</b>			
Family Vespertilionidae			
<i>Chalinolobus tuberculatus</i>	NZ long-tailed bat	North Is, South Is, Stewart Is	L/R
Family Mystacinidae			
<i>Mystacina tuberculata</i>	Lesser NZ short-tailed bat	North Is, South Is, Stewart Is	L/R
<i>M. robusta</i>	Greater NZ short-tailed bat		E
<b>Order Carnivora</b>			
Family Otariidae			
<i>Arctocephalus forsteri</i>	NZ fur seal	North Is, South Is, Stewart Is, Sub-Antarctic Is	L
<i>Phocartos hookeri</i>	NZ sea lion	South Is, Stewart Is, Sub-Antarctic Is	L
Family Pociidae			
<i>Mirounga leonina</i>	Southern elephant seal	Sub-Antarctic Is <sup>1</sup>	L
<i>Leptonychotes weddelli</i>	Weddell seal	Antarctica	W
<i>Hydrurga leptonyx</i>	Leopard seal	Antarctic, Sub-Antarctic Is	W
<i>Lobodon carcinophagus</i>	Crabeater seal	Antarctica	W
<i>Ommatophoca rossi</i>	Ross seal	Antarctica	L/R

<sup>1</sup>Very occasionally recorded on the North and South Islands

much of the remaining forest to make way for agriculture. By the early 1990s, native forest cover stood at around 23%, with improved grasslands making up an estimated 47% of the land cover. Not surprisingly, approximately 90% of New Zealand's pre-human fauna was adapted to living in old growth forests (Stevens *et al.* 1995), a habitat type that was greatly reduced following anthropogenic forest clearing and habitat modification. This, in turn, made endemic species particularly vulnerable to the direct effects of the exotic mammals that accompanied human colonisation through reduced population sizes, a reduction in 'mammal-free' habitat, and subsequent increased encounter rates.

The first recognised human colonists of New Zealand were Polynesian seafarers who arrived approximately 800–1000 years ago (Davidson 1984; Holdaway 1989). The reasons for their arrival are not entirely clear, but they may have included overcrowding on the home islands, foraging expeditions for new resources, or may have been the result of serendipitous discovery by wayward travellers. Whatever the reasons, the first M ori settlers brought two mammal species with them, the Polynesian rat (the kiore *Rattus exulans*) and the now extinct Polynesian dog (the kuri *Canis familiaris*), both of which were used for food. Interestingly, recent evidence suggests that *R. exulans* may have been present in New Zealand for up to 1000 years before the recognised date of human settlement, possibly brought to the country by early Polynesian explorers who did not stay or persist (Holdaway 1996, 1999), although this hypothesis has recently been questioned (see Worthy 2003). There is no accurate or unequivocal information on the impacts of either of these mammals on endemic species in New Zealand, although *C. familiaris* was known to be a skilled hunter of native birds (Anderson 1990) and may have been used by the M ori to hunt moa; large extinct endemic birds in the same family as the kiwi and emu (Anderson 1981).

*Rattus exulans* was widespread throughout the main islands of New Zealand by the time of European settlement, and it was known to undergo periodic population eruptions following synchronous forest-tree seeding. The eruption of rodents in the Nelson and Marlborough regions in the north of the South Island in 1884 was vividly described by Meeson (1885):

"Nelson and Marlborough...[are] enduring a perfect invasion. Living rats are sneaking into every corner, scuttling across every path; their dead bodies in various states of decay, and in many cases more or less mutilated, strew the roads, fields, and gardens, pollute the wells and streams in all directions."

Similarly, the unpleasant effects of a subsequent eruption, on the nearby town of Picton, were eloquently described by Rutland (1890):

"...the whole town was pervaded with the odour of dead rats. It took the place of pastille in the drawing-rooms, and overpowered that of sanctity, even, in the churches."

Hypotheses proposed at the time to explain the eruptions included harsh winters and mass migrations, as well as the large energy input that followed synchronous southern beech *Nothofagus* spp seeding (Rutland 1890). While the

effects of these eruptions on the early settlers are well recorded, exactly what impacts these large increases in rodent numbers had on native flora and fauna remains largely unknown (King 1983). In a recent synthesis, Worthy and Holdaway (2002) identified *R. exulans* as a major, if not the ultimate, cause of local or global extinction for a number of birds, including *Puffinus spelaeus*, Hutton's shearwater *P. huttoni*, the flightless rail *Capellirallus karamu*, Lyall's wren *Traversia lyalli*, and suggested that the species was a significant predator on a wide range of endemic fauna.

Arguably the most damaging consequences of human colonisation have occurred as a result of the European settlement of New Zealand. European exploration and contact started first as a trickle in the late 1700s with the voyages of early explorers, and then as a steady stream of settlers and colonists from the early 1800s (King 1990a). In addition to continuing the widespread habitat modification and land clearing started by the M ori, Europeans were responsible for 96% of the 54 known mammal species introductions into New Zealand. Currently, there are 45 species of land-breeding mammals recognised as being established in New Zealand, of which 36 are introduced, and 9 are endemic or native (Anderson 1990). The native species comprise seven marine mammal species that breed on mainland New Zealand or its Antarctic or sub-Antarctic territories, and two bat species. Without knowing the species that comprise the 9 endemic mammals, it could lead to an underestimate the dominance of exotic mammals in terrestrial systems. In fact, every ground-dwelling mammal in New Zealand has been introduced from elsewhere.

## Humans colonists introduced mammals into New Zealand for five main reasons:

### 1. Food

Both Polynesian and European colonists introduced mammal species as food sources, although both groups also utilised native species to a greater or lesser extent. Although the first M ori settlers brought two species of mammal with them for this purpose (*R. exulans* and *C. familiaris*), the bulk of their protein came from endemic species, particularly the large bird species (including the extinct moa), shellfish and seafood. European colonists, by comparison, introduced a range of domestic and game species to serve as food sources for the developing colony. A number of these species, particularly domestic sheep and cattle, continue to provide much of the food requirements of contemporary New Zealand, as well as forming the basis of important agricultural export industries.

### 2. Resources

Several species were introduced specifically for the resources they could provide, both for the colony itself, and as exports back to England and other global markets. A prime example of this is the Australian brush-tailed possum *Trichosurus vulpecula*, introduced in the 1850s in an attempt to start a fur trade (Cowan 1990). The

industry generated income for the country up until the 1980s, with an estimated 58 million skins exported between 1921–1984, at a value of over \$830 million NZD (1997 value; Warburton *et al.* 2000). However, the species is a known tuberculosis vector, and is now considered to be a major agricultural and ecological pest in New Zealand. Several other mammal species were also introduced for use as resources, including wool producing sheep breeds, and in more recent years, ‘boutique’ species such as Llama *Lama glama* and Alpaca *L. pacos* (King 1990a).

### 3. Acclimatisation and sport

European colonists also introduced an eclectic mix of plants, birds and mammals for more aesthetic reasons. The dense wet New Zealand bush that confronted these first settlers was a far cry from the ‘civilised’ environment that they had left behind, and any object or species that could make their new home feel more familiar was welcomed. Thus, right from the earliest days of settlement, species such as cats *Felis catus*, European dogs *C. familiaris*, rabbits *Oryctolagus cuniculus cuniculus* and hares *Lepus europaeus occidentalis*, as well as wide range of common birds, were introduced (King 1990a; McDowell 1994).

In conjunction with this sentiment, many settlers discovered that New Zealand provided an escape from the rigid class structures established in England, and which had so profoundly influenced their predominantly lower or working class lives. A number of these early European New Zealanders harboured the desire to hunt game species, a privilege denied them under the structured and enforced game preserve system of the British aristocracy (McDowell 1994). McDowell sums the situation up well:

“In the lands from which they came, for most settlers, the species were there to be hunted, but they had few opportunities. By contrast, in early colonial New Zealand there was nothing to prevent them from going hunting or fishing, except that the right species were not present. The problem of getting these opportunities in Great Britain had appeared far more difficult to solve than the problem of making these species available in New Zealand.”

It was these two complementary goals, of importing exotic mammals and other species for their aesthetic and recreational value, which spurred the long process of acclimatisation in New Zealand. Indeed, approximately 44% of the attempted mammal introductions into the country were done to establish sporting game species, while at least a further 15% of attempted species introductions were for companion or aesthetic reasons (King 1990a; McDowell 1994).

### 4. Biological control

It soon became apparent that some of the earlier mammal introductions were having disastrous consequences, although it should be noted that most of these impacts were only seen in the light of agricultural damage or discomfort to humans. Thus, by the mid 1870s, rabbits were causing significant damage to sheep pastures, and

to the economy of the colony (King 1990b). Affected run holders pressed for the introduction of the ‘natural enemies’ of the rabbit, and in 1885, against the protests of early New Zealand ornithologists, government agents liberated a shipment of weasels *Mustela nivalis*, stoats *M. erminea* and ferrets *M. furo* into the central South Island. The importation of these species continued for 20 years (King 1984), by which time all three species had become established throughout New Zealand. *Mustela erminea* in particular has spread throughout the North and South Islands, and it has become a major predator of many native species. The status and impact of the stoat in New Zealand is currently very similar to that of the red fox *Vulpes vulpes* in Australia, where the same mix of fact, fable, uncertainty and concern surrounds the species’ role in natural ecosystems.

It is interesting to note that one other species was brought into New Zealand as a biological control agent, and as a reminder of home. The European hedgehog *Erinaceus europaeus occidentalis* was first introduced by Europeans in Christchurch in 1870 for aesthetic reasons (Brockie 1990). By the 1890s, they had come to be regarded as natural predators of garden pests, and were increasingly imported to control slugs and snails in urban gardens (Brockie 1990). They are now widespread throughout urban and agricultural regions in New Zealand, where they are known to consume native invertebrates, reptiles, and eggs of ground-nesting birds (Berry 1999a, b; Moss 1999; Sanders and Maloney 2002), and which in some cases may have significant impacts (Sanders and Maloney 2002).

### 5. Accidental introductions

Some of the most widespread, successful, and economically and ecologically damaging mammals currently present in New Zealand arrived there accidentally. House mice *Mus domesticus* and Norway rats *R. norvegicus* most probably arrived as stowaways with the first European explorers, whales and sealers in the late 1700s and early 1800s (Moors 1990; Murphy and Pickard 1990). The black rat *R. rattus* is thought to have arrived along with settlers on the first steam powered vessels in the 1850s (Innes 1990). Both *M. domesticus* and *R. rattus* replaced *R. exulans* as the common rodents in forested environments, and together are two of the most ubiquitous mammals present in New Zealand. Both species now undergo the same population eruptions earlier exhibited by *R. exulans* (see above) and, along with *T. vulpecula* and *M. erminea*, have been the focus of much ecological research into their impacts on native species.

### The role of mammals in contemporary New Zealand

It is not a trivial point to state that New Zealand (and Australia) would not be the economically developed countries they are today were it not largely for the presence of introduced domesticated mammals. The domestic mammal species humans brought with them have been instrumental in the exploration and ‘taming’ of the landscape, as well as providing the agricultural basis for the creation of the nation’s wealth (King 1990a). In



comparison, a predominantly different suite of introduced mammal species have also been, and currently are, responsible for some severe environmental problems. It is also important to note that it is only through the creation of such a wealthy society that there is a population with the social will and economic means to consider conserving natural areas and native species. It is within this 'mammal-created' framework that the consideration of the environmental impacts of exotic mammals in New Zealand is conducted. It is not surprising then, that one of the areas where the ecology and impacts of exotic mammals receives the most attention is in agricultural systems. Millions of dollars are spent annually on controlling the impacts of *O. cuniculus cuniculus* on sheep pastures (\$22 million NZD annually in 1995; Parkes 1995), and on controlling the spread of bovine tuberculosis by *T. vulpecula* (\$26 million NZD in 1998/99; Coleman and Livingstone 2000).

Nevertheless, it is in natural systems that introduced mammals have had their most severe ecological and environmental impacts in New Zealand. These interactions can be seen at every trophic level, and in all remaining natural ecosystems. The historical absence of mammalian browsers has meant that the majority of endemic New Zealand woody plants do not produce phenols, terpenes and other secondary metabolic products as anti-browsing defences (Brockie 1992; Clout and Erickson 2000). Consequently, introduced browsing mammals can reach very high and potentially damaging densities, up to 20–25 individuals ha<sup>-1</sup> in the case of *T. vulpecula* in native broadleaf forests (Cowan 1990). In addition, the unbalanced nature of the mammalian fauna introduced into New Zealand means that many species have been introduced without their natural predators. Goats *Capra hircus*, feral pigs *Sus scrofa*, deer *Cervus* spp. and *T. vulpecula* have flourished in a resource rich, predator free environment. *Trichosurus vulpecula* numbers

have been estimated at more than 70 million individuals, with consumption rates of 800–1000g per possum per night (Brockie 1992), or up to 8 million tonnes of vegetation per year (Agresearch New Zealand 2001) mainly from canopy trees. In the 1990s more than \$10 million (NZD) was spent annually on possum control to protect conservation values (Pekelharing *et al.* 1998; Clout and Erickson 2000), which has currently risen to more than c\$12 million NZD annually (Parkes and Murphy 2003). Similarly, grazing and browsing ungulates can significantly alter the composition, structure and biomass of the native communities. It has been estimated that red deer *Cervus elaphus scoticus* can reduce the density of seedlings and saplings of preferred species in native forests by up to 90% (Wardle 1984), while *C. hircus* browsing has resulted in severe soil erosion and significant changes to the structure of native plant communities, particularly in coastal areas and on offshore islands (Rudge 1990). Currently, DOC (Department of Conservation) spends \$6.3 million AUD annually on feral goat control on the New Zealand conservation estate (Parkes and Murphy 2003).

One of the most severe ecological impacts of exotic mammals is predation on native species. Both *R. exulans* and *C. familiaris* were undoubtedly significant predators of invertebrates, and endemic birds and reptiles respectively, although their impacts can be neither accurately quantified or separated from the con-commitment impacts of habitat clearing, burning and human hunting (Atkinson and Moller 1990). The predatory mammals introduced by European colonists have had major impacts on native species. At least 10 species are known to prey upon native fauna, and in some cases significantly so (Table 2). As with the Polynesian-introduced predators, these species' historical and current impacts on the population dynamics and viability of native species are largely unknown. There are, however, several cases where the impacts of introduced mammals on their native prey

**Table 2.** The known impacts of introduced predatory mammals on native New Zealand species. Listed are species recorded in predator diets, as well as those species on which significant impacts are known to occur

Scientific name	Common name	Prey consumed	Examples of significant impact
<i>Mus musculus</i>	House mouse	Seeds and plant material <sup>1</sup> Adult and larval invertebrates: Coleoptera, Lepidoptera <sup>1</sup> Reptiles, Birds <sup>2</sup>	Reptiles <sup>3</sup>
<i>Rattus rattus</i>	Black rat	Adult and larval invertebrates: Aracnidae, Coleoptera, Lepidoptera, Mollusca, Orthoptera, Phasmatidae <sup>4</sup> Amphibians <sup>5</sup> Reptiles <sup>6</sup> Birds <sup>7</sup>	Stewart Island robin ( <i>Petroica australis</i> ), Stewart Island fernbird ( <i>Bowdleria punctata stewartiana</i> ), Stewart Island snipe ( <i>Coenocorypha aucklandica iredalei</i> ), wren ( <i>Xenicus logipes variabilis</i> ), saddleback ( <i>Philesturnus carunculatus</i> ) <sup>8</sup> Kokako ( <i>Callaeus cinerea wilsoni</i> ) <sup>9</sup>
<i>R. norvegicus</i>	Norway rat	Invertebrates: Annelida, Coleoptera, Crustacea, Lepidoptera, Mollusca, Orthoptera, Reptiles, Birds <sup>10</sup>	Native seedlings, invertebrates <sup>11</sup> Campbell Is inverts Pipit ( <i>Anthus novaezeelandia</i> ) <sup>12</sup>
<i>Mustela nivalis</i>	Weasel	Invertebrates: Orthoptera Reptiles Birds Mammals: <i>Mus musculus</i> , Lagomorpha <sup>13</sup>	None known

Scientific name	Common name	Prey consumed	Examples of significant impact
<i>M. erminea</i>	Stoat	Invertebrates: Coleoptera, Lepidoptera, Orthoptera Reptiles Birds Mammals: <i>Erinaceus europaeus occidentalis</i> , Lagomorpha, <i>Mus musculus</i> , <i>Rattus</i> sp. <i>Trichosurus vulpecula</i> <sup>13</sup>	Kiwi ( <i>Apteryx australis</i> ) <sup>14</sup> Yellowhead ( <i>Mohua ochrocephala</i> ) <sup>15</sup> Yellow-eyed penguin ( <i>Megadyptes antipodes</i> ) <sup>16</sup> Seabirds <sup>17</sup> New Zealand dotteral ( <i>Charadrius bicinctus</i> ) <sup>18</sup>
<i>M. furo</i>	Ferret	Invertebrates Fish Amphibians Reptiles Birds Mammals: Lagomorpha, Rodentia, <i>T. vulpecula</i> <sup>19, 20, 21</sup>	<i>Apteryx australis</i> <sup>22</sup> <i>M. antipodes</i> , seabirds <sup>23</sup>
<i>Felis catus</i>	House cat	Invertebrates: Lepidoptera, Coleoptera, Orthoptera Reptiles <sup>24</sup> Birds <sup>25, 26</sup> Mammals: Lagomorpha, <i>M. musculus</i> , <i>R. rattus</i> , <i>R. norvegicus</i> , <i>T. vulpecula</i> <sup>26</sup>	Stephens Island wren ( <i>Philesturnus carunculatus</i> ), yellow-crowned parakeet ( <i>Cyanoramphus auriceps</i> ), robin ( <i>Petroica australis</i> ), fernbird ( <i>Bowdleria punctata</i> ), brown creeper ( <i>Finschia novaeseelandiae</i> ), snipe ( <i>Coenocorypha aucklandica</i> ), banded rail ( <i>Rallus philippensis</i> ), broad-billed prions ( <i>Pachyptila vittata</i> ) <sup>27</sup> Wedge-tailed shearwater ( <i>Puffinus pacificus</i> ), Kermadec petrel ( <i>Pterodroma neglecta</i> ), black-winged petrel ( <i>P. nigripennis</i> ), Kermadec parakeet ( <i>Cyanoramphus novaeseelandiae cyanurus</i> ) <sup>28</sup> Stichbird ( <i>Notiomystis cincta</i> ), <i>P. carunculatus</i> , red-crowned parakeet ( <i>C. novaeseelandiae</i> ) <sup>29</sup>
<i>Canis familiaris</i>	Domestic dog	Unknown <sup>30</sup>	Kiwi ( <i>Apteryx australis</i> ) <sup>31</sup>
<i>Trichosurus vulpecula</i>	Brush-tailed possum	Plant material: leaves, fruit, flowers and bugs from native and exotic species Invertebrates: Coleoptera, Diptera, Orthoptera, Phasmatidae <sup>32</sup> Birds <sup>9, 14</sup>	<i>C. cinerea wilsoni</i> <sup>9</sup> Snails <sup>33</sup>
<i>Sus scrofa</i>	Feral pig	Plant material: grasses, legumes, roots and herbs Invertebrates: Amphipoda, Annelidae, Coleoptera, Diplopoda, Mollusca Amphibians Reptiles Birds Mammals: Lagomorphs, Rodentia <sup>34, 35</sup>	Giant land-snail ( <i>Powelliphanta</i> sp. <sup>35</sup> , <i>Placostylus ambagiosis</i> <sup>36</sup> )

<sup>1</sup>Lepidoptera and coleoptera (Baden 1986); <sup>2</sup>(Pickard 1984; Ruscoe 2001); (Newman 1994) <sup>4</sup>Beetles, spiders, stick insects, weta, lepidoptera (Innes 1979; Gales 1982); <sup>5</sup>(Eggers 1998); <sup>6</sup>(Whitaker 1978); <sup>7</sup>(Atkinson 1985; Innes 1990); <sup>8</sup>(Innes 1990); <sup>9</sup>(Innes et al. 1999); <sup>10</sup>(Moors 1990); <sup>11</sup>(Allen et al. 1994); <sup>12</sup>(Moors 1990); <sup>13</sup>(King and Moody 1982); <sup>14</sup>(McLennan et al. 1996); <sup>15</sup>(Dilks 1999); <sup>16</sup>(Moller and Alterio 1999); <sup>17</sup>(Lyver 2000); <sup>18</sup>(Dowding and Murphy 1996); <sup>19</sup>(Roser and Lavers 1976); <sup>20</sup>(Pierce 1986); <sup>21</sup>(Clapperton 2001); <sup>22</sup>(McLennan et al. 1996); <sup>23</sup>(Clapperton 2001); <sup>24</sup>(Karl and Best 1982); <sup>25</sup>(Fitzgerald and Karl 1979; Fitzgerald and Vietch 1985; Pierce 1986); <sup>26</sup>(Fitzgerald 1990); <sup>27</sup>Local extinction following liberation onto Herekopare Island: (Fitzgerald and Vietch 1985); <sup>28</sup>Local extinctions on Raoul Island: (Merton 1970); <sup>29</sup>Species showed significant population increases following cat removal: (Vietch 1985); <sup>30</sup>Wild dogs are rare in New Zealand, and generally consist of escaped domestic animals. Individuals have been known to take sheep in isolated incidents, but no information on their broader diet is available; <sup>31</sup>One German shepherd is believed to have killed at least 500 individual kiwi in Northland, but the frequency and severity of these attacks is unknown: (Taborsky 1988); <sup>32</sup>(Cowan 1990); <sup>33</sup>(Cowan 2001); <sup>34</sup>(Meads et al. 1984); <sup>35</sup>(McIlroy 1990); <sup>36</sup>(Sherley et al. 1998).

are well documented. *Mustela erminea* is a major predator of kiwi populations, with up to 60% of chicks removed by predation before fledging. Combined with other causes of chick mortality, this results in a 95% chick mortality rate and declines in kiwi populations of around 6% per year (McLennan *et al.* 1996). *Mustela erminea* must be reduced by at least 80% for chick recruitment to rise above the population replacement level of 20%, and a number of programs are currently underway to achieve these levels of predator reduction and kiwi recruitment (Bassett and Potter 2001; McLennan Landcare Research Ltd pers. comm.). Research into the causes of decline in the North Island kokako *Callaeus cinerea wilsoni*, an endemic wattlebird, has identified predation by *R. rattus* and *T. vulpecula* as the two major causal factors (Innes *et al.* 1999). An 'adaptive management' framework, combining poisoning operations and monitoring of *R. rattus*, *T. vulpecula* population responses has resulted in significant increases in kokako populations in treatment areas (Innes *et al.* 1999). Other examples include work on the impacts of stoats on the endemic passerine the Mohua (Elliott 1996) and Hutton's shearwaters (Cuthbert *et al.* 2001; Cuthbert and Davis 2002).

However, information on the population dynamics, ecology and interactions of both native species and introduced mammals is usually too sparse to allow any real clear understanding of the conservation status of many native species. We only become aware of a problem when the study species has reached a critically low level, and drastic and costly actions are required. This is the so called 'conservation crisis' (Linklater 2003), in which research into the problem often lags behind the information required to enact successful management actions. It is a common problem in ecology and conservation globally. While a range of research into the basic biology of introduced mammals in New Zealand has been conducted, there is still a critical lack of information about the ecology, and role, of exotic mammals in New Zealand ecosystems (Blackwell and Linklater 2003), which can potentially limit the efficacy of desired conservation actions.

## The role and nature of mammalogy in contemporary New Zealand

The historical origins of mammals in New Zealand, and their impacts on native species and ecosystems, have shaped the framework in which mammals are perceived and researched in that country. While endemic species and ecosystems are viewed as intrinsically valuable and worthy of conservation, introduced mammals are still viewed as 'exotic' and 'unwelcome', and as not being part of natural systems (King 1990a). In an environmental context, 'mammal' is largely synonymous with 'pest', and 'mammalogy' with 'pest management', and research on introduced species has been predominantly conducted in this context. Of 108 papers published on the six most common taxa of exotic mammals in natural systems in New Zealand between 1990 and 2000, 66% focussed on the impacts of the study species on native flora and fauna and on ways to minimise these impacts. In comparison, 21% of papers studied the 'pure' biology or ecology of exotic mammals without a conservation basis, and only

13% of papers used exotic mammals to address larger questions in ecology (Blackwell and Linklater 2003). In comparison, 25 papers were published on native New Zealand bats over the same period, of which 48% of these studies described basic biology, and 40% investigated theoretical issues in ecology. The majority of ecological research on mammals in New Zealand has been on the nature and severity of impacts of introduced species.

This situation is in contrast to the study of mammalogy in regions with large endemic mammal faunas, such as Australia, North America and Europe. While the ecology of introduced mammals is an important branch of the science in these countries (for example, the large body of research into the ecology and impacts of feral *F. catus* and *V. vulpes* introduced into Australia), the majority of research has been on the ecology of mammals endemic or native to the region. Again, this situation reflects the composition of the local fauna and the relative anthropogenic value given to endemic and exotic species. As an example, between 1990-2000, 174 and 53 papers were published on *T. vulpecula* in New Zealand and Australia respectively (Blackwell and Linklater 2003). The focus of research was significantly different between the two countries, with over 80% of New Zealand studies investigating pest impacts or control and monitoring techniques, compared to 17% of Australian studies. In comparison, only 4.5% of New Zealand studies used *T. vulpecula* to investigate theoretical issues in ecology, as opposed to 53% of Australian studies. The differences in the nature and relative focus of mammalogy between New Zealand and countries, such as Australia, have a number of consequences for the way in which the science is conducted.

Most of the theories and advances in 'pure' mammalogy come from outside New Zealand, and are then applied to local systems. For example, studies on eruptive rodents in New Zealand draw almost entirely on the theoretical developments of researchers working on similar systems in Australia (Newsome *et al.* 1989; Pech *et al.* 1995; Sinclair *et al.* 1998) and elsewhere (Pucek *et al.* 1993; Wolff 1996; Schnurr *et al.* 2002). While the nature of the population eruptions of *M. domesticus*, *R. rattus* and *M. erminea* have been known in New Zealand for many decades (Fitzgerald 1978; King 1983; Fitzgerald *et al.* 1996), and their impacts on native species assumed (King 1983, 1984), the explicit investigation of the mechanisms underlying these process and their ecological implications has only occurred relatively recently (Fitzgerald *et al.* 1996; Choquenot and Ruscoe 2000; Blackwell *et al.* 2001). New Zealand mammalogists have certainly made major contributions to the field of ecology; the seminal work of Caughley on ungulate dispersal (Caughley 1963) and demographics (Caughley 1966) is a case in point. Nevertheless, in many respects, mammalogy in New Zealand has been insular, and there is a great need for the science to be placed in a larger global context.

Conversely, New Zealand practitioners of mammalogy/pest management have significantly refined and developed the science. The knowledge, skill, and ability exists in New Zealand to allow large-scale control of mammal species that are pests in both New Zealand and elsewhere, including

Australia. New Zealand pest managers have the ability to clear large islands of introduced rodents, such as Kapiti Island at 5,000 ha (Empson and Miskelly 1999) and subantarctic Campbell Island at 11,000 ha (this program is currently awaiting confirmation of success; (McClelland and Tyree 2002). Similarly, the 'Judas Goat' program, where individuals of *C. hircus* are radio-tracked back to their herd allowing the efficient location and destruction of pest populations (Parkes 1983; Rudge 1990), illustrates the expertise of New Zealand scientists and pest managers. Such knowledge can be used in the management of pest mammals internationally, and indeed, such knowledge transfer has and is continuing to occur (Taylor *et al.* 2000; Millet and Shah 2001).

The perception of mammals in New Zealand also raises some important ethical and moral issues. Problems must be considered at a range of complementary, and sometimes conflicting, levels. As an example, once the primarily moral decision has been made that it is unethical to allow *T. vulpecula* to affect large areas of native forest, there is an obligation at the level of the individual possum to ensure that any control methods are ethically acceptable, and control methods must comply with animal ethics standards under New Zealand law. Such concerns also affect the way that decisions are made regarding other control techniques. Efforts to develop biological control agents to reduce pest mammal impacts must be considered in the light of possible repercussions for that species and others in their natural range. This is a problem that affects research into the potential biological control of *T. vulpecula* in New Zealand, and of *V. vulpes* in Australia. The status and 'worth' of species may also vary between different groups in society, and can lead to operational dilemmas for conservation managers. Prime examples in both Australia and New Zealand are introduced ungulate species, which are known to cause significant damage to native flora, but where efforts to reduce numbers or remove individual populations often meet with opposition from concerned interest groups.

The key challenges for mammalogy in New Zealand are to synthesise the two alternative approaches currently being practised. Basic and theoretical research is required into the ecology of introduced mammals in New Zealand if the contemporary role of these species in natural systems is to be understood. Armed with accurate knowledge, the

appropriate response from the array of successful pest management strategies can then be implemented.

However, exotic mammals in New Zealand (and Australia) provide an opportunity to make important advances in our ecological understanding (Kitching 1986; King 1990a, 2001). In both countries there are species of introduced mammals, such as the introduced murid rodents (*M. domesticus* and *R. rattus*), *O. cuniculus cuniculus*, *F. catus*, and several species of ungulate, including *C. elaphus scoticus*, sambar *C. unicolor*, *S. scrofa* and *C. hircus*, that are widespread, well-researched elsewhere, and amenable to experimental manipulation and investigation. There are many fields, both traditional and at the frontiers of ecology, in which research into exotic mammal species in Australasia could serve as model systems (Blackwell and Linklater 2003). Examples of ways exotic mammals have been used in this manner include the investigation of sub-fossil *R. exulans* deposits to provide an insight into pre-historic human movements and settlement in the Pacific (Matisoo-Smith *et al.* 1998); the use of Himalayan tahr *Hemitragus jemlahicus* and chamois *Rupicapra rupicapra* to demonstrate current competition between two species with no common co-evolutionary history (Forsyth and Hickling 1988); the use of *T. vulpecula* in New Zealand to investigate ecological adaptation to a new environment in action (Cowan 1990); and the investigation of rodent/mustelid eruptive systems to help understand the factors regulating population structure and dynamics (Fitzgerald *et al.* 1996; Choquenot and Ruscoe 2000; Blackwell *et al.* 2001). King (2001) succinctly summed up the situation facing New Zealand mammalogists when she wrote:

"The interactions we observe, within the mammal fauna and between the mammals and their environments, are not 'natural', but together they make up a working, evolving community, which we must manage as best we can."

The contemporary mammals of New Zealand form a globally unique assemblage, with novel species combinations, population dynamics and ecological roles. This has had profound consequences for the endemic flora and fauna of the country. Consequently, mammalogy in New Zealand is, and will continue to be, a dynamic, unique and challenging science, with an important role to play in increasing understanding of ecological systems and our place in them.

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## References

- Agresearch New Zealand. 2001. Agresearch Educational Outreach. <http://www.agresearch.co.nz/scied/search/biocontrol/pests.htm>. Accessed 14 July 2004.
- Allen, R.B., Lee, W.G. and Rance, B.D. 1994. Regeneration in indigenous forest after eradication of Norway rats, Breaksea Island, New Zealand. *New Zealand Journal of Botany* 32: 429-439.
- Anderson, A. 1981. Pre-European hunting dogs in the South Island, New Zealand. *New Zealand Journal of Archaeology* 3: 15-20.
- Anderson, A.J. 1990. Kuri. Pp. 277-287 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.



- Atkinson, I.A.E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pp. 35-81 in *Conservation of Island Birds*, edited by P.J. Moors. International Council for Bird Preservation.
- Atkinson, I.A.E. and Moller, H. 1990. Kiore. Pp. 175-192 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- Augee, M. and Fox, M. 2000. *Biology of Australia and New Zealand*. Pearson Education Australia, Sydney.
- Baden, D. 1986. Diet of the house mouse (*Mus musculus* L.) in two pine forests and a kauri forest. *New Zealand Journal of Ecology* 9: 137-141.
- Bassett, S.M. and Potter, M.A. 2001. Comparison of two regimes for artificially incubating kiwi eggs. Department of Conservation, 342, Wellington.
- Berry, C.J.J. 1999a. European hedgehogs (*Erinaceus europaeus* L.) and their significance to the ecological restoration of Boundary Stream Mainland Island, Hawkes Bay. M. Cons. Sci. thesis, Victoria University.
- Berry, C.J.J. 1999b. Potential interactions of hedgehogs with North Island brown kiwi at Boundary Stream Mainland Island. Department of Conservation, Wellington.
- Blackwell, G.L. and Linklater, W.L. 2003. Unique and valuable but untouched research opportunities using exotic mammals in Australasia. *Australian Zoologist* 32: 420-430.
- Blackwell, G.L., Potter, M.A. and Minot, E.O. 2001. Rodent and predator population dynamics in an eruptive system. *Ecological Modelling* 142: 227-245.
- Brockie, R. 1992. *A Living New Zealand Forest*. David Bateman, Auckland.
- Brockie, R.E. 1990. Hedgehog. Pp. 99-113 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- Caughley, G. 1963. Dispersal rates of several ungulates introduced into New Zealand. *Nature* 200: 280-281.
- Caughley, G. 1966. Mortality patterns in mammals. *Ecology* 47: 906-918.
- Choquenot, D. and Ruscoe, W.A. 2000. Mouse population eruptions in New Zealand forests: the role of population density and seedfall. *Journal of Animal Ecology* 69: 1058-1070.
- Clapperton, B.K. 2001. Advances in New Zealand mammalogy 1990-2000: Feral ferret. *Journal of the Royal Society of New Zealand* 31: 185-203.
- Clout, M. and Erickson, K. 2000. Anatomy of a disastrous success. The brushtail possum as an invasive species. Pp. 1-9 in *The Brushtail Possum: Biology, Impact and Management of an Introduced Marsupial*, edited by T.L. Montague. Manaaki Whenua Press, Lincoln.
- Coleman, J. and Livingstone, P. 2000. Fewer possums: less bovine TB. Pp. 220-231 in *The Brushtail Possum: Biology, Impact and Management of an Introduced Marsupial*, edited by T.L. Montague. Manaaki Whenua Press, Lincoln.
- Cooper, R.A. and Millener, P.R. 1993. The New Zealand biota: historical background and new research. *Trends in Ecology and Evolution* 8: 429-433.
- Cowan, P.E. 1990. Brushtail possum. Pp. 68-98 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- Cowan, P.E. 2001. Advances in New Zealand mammalogy 1990-2000: Brushtail possum. *Journal of the Royal Society of New Zealand* 31: 15-29.
- Cuthbert, R. and Davis, L.S. 2002. The impact of predation by introduced stoats on Hutton's shearwaters, New Zealand. *Biological Conservation* 108: 79-92.
- Cuthbert, R.J., Sommer, E.S. and Davis, L.S. 2001. Diet of stoats in a shearwater colony. *New Zealand Journal of Zoology* 27: 367-373.
- Daugherty, C.H., Gibbs, G.W. and Hitchmough, R.A. 1993. Mega-island or micro-continent? New Zealand and its fauna. *Trends in Ecology and Evolution* 8: 437-442.
- Davidson, J. 1984. *The Prehistory of New Zealand*. Longman Paul, London.
- Dilks, P. 1999. Recovery of a Mohua (*Mohua ochrocephala*) population predator control in the Eglinton Valley, Fiordland, New Zealand. *Notornis* 46: 323-332.
- Dowding, J.E. and Murphy, E.C. 1996. Predation of northern New Zealand dotterels (*Charadrius obscurus aquilonius*) by stoats. *Notornis* 43: 144-146.
- Eggers, K.E. 1998. Morphology, ecology and development of leiopelmatid frogs (*Leiopelma* spp.), in Whareorino Forest, New Zealand. M.Sc thesis, Massey University.
- Elliott, G.P. 1996. Mohua and stoats: A population viability analysis. *New Zealand Journal of Zoology* 23: 239-247.
- Empson, R.A. and Miskelly, C.M. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *New Zealand Journal of Ecology* 23: 241-254.
- Fitzgerald, B.M. 1978. Population ecology of mice in New Zealand. Pp. 163-171 in *The Ecology and Control of Rodents in New Zealand Nature Reserves*, edited by C. Hay. The Department of Lands and Survey, Wellington.
- Fitzgerald, B.M. 1990. House cat. Pp. 330-348 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- Fitzgerald, B.M., Daniel, M.J., Fitzgerald, A.E., Karl, B.J., Meads, M.J. and Notman, P.R. 1996. Factors affecting the numbers of house mice (*Mus musculus*) in hard beech (*Nothofagus truncata*) forest. *Journal of the Royal Society of New Zealand* 26: 237-249.
- Fitzgerald, B.M. and Karl, B.J. 1979. Food of feral house cats (*Felis catus* L.) in forest of the Orongorongo Valley, Wellington. *New Zealand Journal of Zoology* 6: 107-126.
- Fitzgerald, B.M. and Vietch, C.R. 1985. The cats of Herekopare Island, New Zealand; their history, ecology and effects on birdlife. *New Zealand Journal of Zoology* 12: 319-330.
- Forsyth, D.M. and Hickling, G.J. 1988. Increasing Himalayan tahr and decreasing chamois densities in the eastern Southern Alps, New Zealand: evidence for interspecific competition. *Oecologia* 113: 377-382.
- Gales, R.P. 1982. Age- and sex-related differences in diet selection by *Rattus rattus* on Stewart Island, New Zealand. *New Zealand Journal of Zoology* 9: 463-466.
- Holdaway, R.N. 1989. New Zealand's pre-human fauna and its vulnerability. *New Zealand Journal of Ecology* 12: 11-25.
- Holdaway, R.N. 1996. Arrival of rats in New Zealand. *Nature* 384: 225-226.
- Holdaway, R.N. 1999. A spatio-temporal model for the invasion of the New Zealand archipelago by the Pacific rat *Rattus exulans*. *Journal of the Royal Society of New Zealand* 29: 91-105.
- Innes, J. 1990. Ship rat. Pp. 206-225 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.

- Innes, J., Hay, R., Flux, I., Bradfield, P., Speed, H. and Jansen, P. 1999. Successful recovery of the North Island kokako (*Callaeus cinerea wilsoni*) populations, by adaptive management. *Biological Conservation* 87: 201-214.
- Innes, J.G. 1979. Diet and reproduction of ship rats in the northern Tararua. *New Zealand Journal of Ecology* 2: 85-86.
- Karl, B.J. and Best, H.A. 1982. Feral cats on Stewart Island; their foods and their effects on kakapo. *New Zealand Journal of Zoology* 9: 287-294.
- King, C.M. 1983. The relationship between beech (*Nothofagus* sp.) seedfall and populations of mice (*Mus musculus*), and the demographic and dietary responses of stoats (*Mustela erminea*), in three New Zealand forests. *Journal of Animal Ecology* 52: 141-166.
- King, C.M. 1984. *Immigrant killers. Introduced Predators and the Conservation of Birds in New Zealand*. Oxford University Press, Auckland.
- King, C.M. 1990a. *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland.
- King, C.M. 1990b. Stoat. Pp. 288-312 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- King, C.M. 2001. Advances in New Zealand Mammalogy, 1990-2000: Introduction. *Journal of the Royal Society of New Zealand* 31: 1-5.
- King, C.M. and Moody, J.E. 1982. The biology of the stoat in the national parks of New Zealand. *New Zealand Journal of Zoology* 9: 49-144.
- Kitching, R.L. 1986. *The Ecology of Exotic Animals and Plants: Some Australian Case Histories*. John Wiley and Sons, Brisbane.
- Linklater, W.L. 2003. Science and management in a conservation crisis: A case study with rhinoceros. *Conservation Biology* 17: 968-975.
- Lyver, P.O. 2000. Identifying mammalian predators from bite marks: a tool for focusing wildlife protection. *Mammal Review* 30: 31-43.
- Matisoo-Smith, E., Roberts, R.M., Irwin, G.J., Allen, J.S., Penny, D. and Lambert, D.M. 1998. Patterns of prehistoric human mobility in Polynesia indicated by mtDNA from the Pacific rat. *Proceedings of the National Academy of Sciences of the United States of America* 95: 15145-15150.
- McClelland, P. and Tyree, P. 2002. Eradication: the clearance of Campbell Island. In *New Zealand Geographic*. pp. 86-94.
- McDowell, R.M. 1994. *Gamekeepers for the Nation: the Story of New Zealand's Acclimatization Societies 1861-1990*. Canterbury University Press, Christchurch.
- McIlroy, J.C. 1990. Feral pig. Pp. 358-371 in *The Handbook of New Zealand Mammals*. edited by C.M. King. Oxford University Press, Auckland.
- McLennan, J.A., Potter, M.A., Robertson, H.A., Wake, G.C., Colbourne, R., Dew, L., Joyce, L., McCann, A.J., Miles, J., Miller, P.J. and Reid, J. 1996. Role of predation in the decline of kiwi, *Apteryx* spp., in New Zealand. *New Zealand Journal of Ecology* 20: 27-35.
- McNab, B.K. 1994. Energy conservation and the evolution of flightlessness in birds. *American Naturalist* 144: 628-642.
- Meads, M.J., Walker, K.J. and Elliott, G.P. 1984. Status, conservation and management of the land snails of the genus *Powelliphanta* (Mollusca: Pulmonata). *New Zealand Journal of Zoology* 11: 277-306.
- Meeson, J. 1885. The plague of rats in Nelson and Marlborough. *Transactions of the New Zealand Institute* 17: 199-207.
- Merton, D.V. 1970. Kermadec Islands expedition reports: a general account of birdlife. *Notornis* 17: 147-199.
- Millet, J. and Shah, N.L. 2001. Eradication of rats from Fregate Island, Seychelles. *Bird Conservation International* 11: 149-150.
- Moller, H. and Alterio, N. 1999. Home range and spatial organisation of stoats (*Mustela erminea*), ferrets (*Mustela furo*) and feral house cats (*Felis catus*) on coastal grasslands, Otago Peninsula, New Zealand: implications for yellow-eyed penguin (*Megadyptes antipodes*) conservation. *New Zealand Journal of Zoology* 26: 165-174.
- Moors, P.J. 1990. Norway rat. Pp. 192-206 in *The handbook of New Zealand Mammals*. edited by C.M. King. Oxford University Press, Auckland.
- Moss, K.A. 1999. Diet, nesting behaviour, and home range size of the European hedgehog (*Erinaceus europaeus*) in the braided rivers of the Mackenzie Basin, New Zealand. Master of Science thesis, University of Canterbury.
- Murphy, E.C. and Pickard, C.R. 1990. House mouse. Pp. 225-242 in *The Handbook of New Zealand Mammals*. edited by C.M. King. Oxford University Press, Auckland.
- Newman, D.G. 1994. Effects of a mouse, *Mus musculus*, eradication program and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregor's skink, *Cyclodina macgregori*. *New Zealand Journal of Zoology* 21: 443-456.
- Newsome, A.E., Parer, I. and Catling, P.C. 1989. Prolonged Prey Suppression by Carnivores - Predator-Removal Experiments. *Oecologia* 78: 458-467.
- Parkes, J. and Murphy, E. 2003. Management of introduced mammals in New Zealand. *New Zealand Journal of Zoology* 30: 335-359.
- Parkes, J.P. 1983. Control of feral goats by poisoning with compound 1080 on natural vegetation baits, and by shooting. *New Zealand Journal of Forestry Science* 13: 266-274.
- Parkes, J.P. 1995. Rabbits as pests in New Zealand: a summary of the issues and critical information. Landcare Research Report, LC495/141.
- Pech, R.P., Sinclair, A.R.E. and Newsome, A.E. 1995. Predation models for primary and secondary prey species. *Wildlife Research* 22: 55-64.
- Pekelharing, C.J., Frampton, C.M. and Suisted, P.A. 1998. Seasonal variation in the impacts of brushtailed possums (*Trichosurus vulpecula*) on five palatable species of New Zealand beech (*Nothofagus*) forest. *New Zealand Journal of Ecology* 22: 141-148.
- Pickard, C.R. 1984. The population ecology of the house mouse (*Mus musculus*) on Mana Island. M.Sc thesis, Victoria University.
- Pierce, R.J. 1986. Differences in susceptibility to predation during nesting between pied and black silts (*Himantopus* spp.). *Auk* 103: 273-280.
- Pucek, Z., Jedrzejewski, W., Jedrzejewska, B. and Pucek, M. 1993. Rodent Population-Dynamics in a Primeval Deciduous Forest (Bialowieza-National-Park) in Relation to Weather, Seed Crop, and Predation (Vol 38, Pg 199, 1993). *Acta Theriologica* 38: U233-U233.
- Roser, R.J. and Lavers, R.B. 1976. Food habits of the ferret (*Mustela putorius furo* L.) at Pukepuke Lagoon, New Zealand. *New Zealand Journal of Zoology* 3: 269-275.

- Rudge, M.R. 1990.** Feral goat. Pp. 406-423 in *The Handbook of New Zealand Mammals*, edited by C.M. King. Oxford University Press, Auckland.
- Ruscoe, W.A. 2001.** Advances in New Zealand mammalogy 1990-2000: House mouse. *Journal of the Royal Society of New Zealand* **31**: 127-134.
- Rutland, J. 1890.** On the habits of the New Zealand bush rat. *Transactions of the New Zealand Institute* **22**: 300-307.
- Sanders, M.D. and Maloney, R.F. 2002.** Causes of mortality at nests of ground-nesting birds in the Upper Waitaki Basin, South Island, New Zealand: a 5-year video study. *Biological Conservation* **106**: 225-236.
- Schnurr, J.L., Ostfeld, R.S. and Canham, C.D. 2002.** Direct and indirect effects of masting on rodent populations and tree seed survival. *Oikos* **96**: 402-410.
- Sherley, G.H., Stringer, I.A.N., Parrish, G.R. and Flux, I. 1998.** Demography of two landsnail populations (*Placostylus ambagiosus*, Pulmonata : Bulimulidae) in relation to predator control in the far north of New Zealand. *Biological Conservation* **84**: 83-88.
- Sinclair, A.R.E., Pech, R.P., Dickman, C.R., Hik, D., Mahon, P. and Newsome, A.E. 1998.** Predicting effects of predation on conservation of endangered prey. *Conservation Biology* **12**: 564-575.
- Stevens, G., McGlone, M. and McCulloch, B. 1995.** *Prehistoric New Zealand*. Reed, Auckland
- Strahan, R. (Ed.) 1995.** *The Mammals of Australia*. Reed New Holland, Sydney.
- Taborsky, M. 1988.** Kiwis and dog predation: observations in Waitangi State Forest. *Notornis* **35**: 197-202.
- Taylor, R.H., Kaiser, G.W. and Drever, M.C. 2000.** Eradication of Norway rats for recovery of seabird habitat on Langara Island, British Colombia. *Restoration Ecology* **8**: 151-160.
- Towns, D.R. and Ballantine, W.J. 1993.** Conservation and restoration of New Zealand island ecosystems. *Trends in Ecology and Evolution* **8**: 452-457.
- Vietch, C.R. 1985.** Methods of eradicating feral cats from offshore islands in New Zealand. Pp. 125-141 in *Conservation of Island Birds*, edited by P.J. Moors. International Council for Bird Preservation.
- Warburton, B., Toucher, G. and Allan, N. 2000.** Possums as a resource. Pp. 251-261 in *The Brushtail Possum: Biology, Impact and Management of an Introduced Marsupial*, edited by T.L. Montague. Manaaki Whenua Press, Lincoln.
- Wardle, J.A. 1984.** *The New Zealand Beeches, Ecology, Utilisation and Management*. NZ Forest Service, Wellington.
- Webb, C.J. and Kelly, D. 1993.** The reproductive biology of the New Zealand flora. *Trends in Ecology and Evolution* **8**: 442-447.
- Whitaker, A.H. 1978.** The effects of rodents on reptiles and amphibians. Pp. 75-86 in *The Ecology and Control of Rodents in New Zealand Nature Reserves*, edited by C. Hay. The Department of Lands and Survey, Wellington.
- Wolff, J.O. 1996.** Population fluctuations of mast-eating rodents are correlated with production of acorns. *Journal of Mammalogy* **77**: 850-856.
- Worthy, T.H. 2003.** Origin, taxonomy and palaeoecology of New Zealand birds - a review of recent advances in the palaeontological arena. Pp. 12-13 in *The 2003 Australasian Ornithological Conference*, Canberra.
- Worthy, T.H. and Holdaway, R.N. 2002.** *The Lost World of the Moa: Prehistoric Life in New Zealand*. Canterbury University Press, Christchurch.